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Sustaining Rice Productivity, Soil Fertility, and Income from Prawn-Rice Joint Culture in the Gher System in Bangladesh

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Sustaining Rice Productivity, Soil Fertility and Income from ‘Prawn-rice’ Joint Culture in the Gher System in Bangladesh

ABSTRACT

This paper examines long-term impacts of joint prawn-rice ‘gher’ farming system on agricultural and household income, soil fertility and productivity of modern variety (MV) rice in southwestern Bangladesh. The study used socio-economic data of the gher farmers along with soil fertility data of their gher plots. Twenty farmers operating on 30 plots were randomly selected from the Bilpabla village of Khulna in 2005. Production data on prawn and MV rice were collected using a comprehensive questionnaire. Soil samples were also collected and tested in the Soil Resources Development Institute (SRDI). To assess sustainability of the gher system over time, same farmers and plots were surveyed in 2011 and 2017 following the same methodology. Results revealed that although the nominal income from gher farming increased by 59% in 2011 and 23% in 2017, the real income and per capita household income remained unchanged over time. Agricultural income has contributed about 65% to household income and household income of gher farmers was about 200% higher than the rural people of Bangladesh. Rice productivity declines slightly from its 2005 level. However, the productivity of MV rice under prawn-rice gher farming is substantially higher than the conventional MV rice farming system. The estimated values of the Mean Soil Quality Index (MSQI) and Soil Degradation Index (SDI) were positive for land used for MV paddy production within the gher, indicating an increase in soil nutrients. Therefore, it can be concluded that the joint prawn-rice gher farming system is relatively sustainable as it has improved soil fertility and stabilized real income. Policy implications include research on developing varieties of MV rice suited to prawn-rice gher farming system and the development of commercial feeds and markets for prawn to increase productivity vis-à-vis income of gher farmers and to promote agricultural growth in the southwestern region of Bangladesh.

Keywords: Soil fertility; MV rice productivity; Income; Prawn-rice gher farming; Bangladesh

INTRODUCTION

Transformation of agricultural land results in changes in cropping patterns along with ecosystem and the surrounding environment. Rice fields have been transformed into shrimp/prawn farming in coastal areas of tropical Asia and Latin America which has substantially changed the land use patterns of these areas (Ali 2006). The land use patterns of southern coastal region of Bangladesh covering Bagherhat, Satkhira and Khulna districts have been substantially influenced by soil intrusion, salinity and unavailability of ground water for irrigation for MV rice cultivation and other dry-season crops. In fact, the proportion of fallow land has increased over the years due to soil salinization and scarcity of freshwater for irrigation in the region (SRDI 2012; Kabir et al. 2015).

Shrimp/prawn farming has been recognized as a part of the Blue Revolution in southern part of Bangladesh since mid-1980s and has made significant contributions to the local and national economy through foreign exchange earnings and food for coastal residents (Kabir and Eva 2014; Paul and Vogl 2011; Ahamed et al. 2012). Large numbers of male and female worker have been directly or indirectly engaged in different activities of shrimp/prawn farming in Bangladesh. Apart from the overall positive financial and food contribution to the local and national economy, shrimp/prawn farming is posing severe threats to the local ecological and environmental systems, such as soil degradation, soil sedimentation, salinization, pollution and deterioration of water quality in terms of saline intrusion in ground water, depletion of mangrove forest, local indigenous fish and local varieties of rice in southern Bangladesh (Wahab 2003; Hoq 1999; Islam 2003; Ali 2004; Hossain et al. 2013; Eva 2012).

Commercial shrimp farming has spread and increased rapidly from mid-1980's in southwestern Bangladesh simply due to high international market demand and the tendency to make quick money and/or income (Deb 1998; Neiland et al. 2001; Barmon et al. 2004b). The shrimp-rice farming exerts negative impacts on the environment and ecology (Deb 1998; Dewalt et al. 1996; Flaherty et al. 1999; Ali 2004). Also, prolonged shrimp farming has rapidly diminished soil quality in rice fields and reduced rice productivity substantially. In other words, soil quality of rice fields has degraded significantly after the introduction shrimp farming in southwest Bangladesh. (Ali 2004; Ali 2006).

Prawn-rice joint culture in the gher system is an indigenous technology combining aquaculture and agriculture developed and used by local farmers in Southwestern Bangladesh since mid-1980s. The term 'gher' refers to modification of rice field that has been used for prawn and MV rice cultivation. The mid-field (locally known as *chatal*) of gher is surrounded by high and wide dikes and canals lying in the periphery of the dikes. The whole area of gher is filled with rainwater from June to December and resembles to a pond and is used to cultivate freshwater prawn

(*Macrobrachium rosenbergii*) and carp. The entire plot becomes dry naturally from January to April except canals. The canals retain enough volume of water for MV boro season (dry winter) rice cultivation during this time.

Prior to gher farming, the southwest region experienced a period of severe environmental change during 1960s and 1980s because of the construction of embankments and polders which resulted in permanent water logging and increased saline intrusion causing adverse impact on the production of agricultural crops (Kendrick 1994). After the adoption of gher farming system, the cropping patterns have changed thus permitting farmers to produce prawn and MV rice together in a year.

Although the impact of shrimp-rice farming on the environment and ecology in the coastal region of Bangladesh was studied by some researchers (e.g., Asaduzamman et al. 1998; Aftabuzzaman 1998; Nijera Kori 1996; Bhattacharya et al. 1999; Rahman 1998; Islam 2003; Ahmed and Garnett 2010; Datta 2001; Islam 2001), similar study on the prawn-rice gher farming system is not widely available in the literature. Instead, most of the studies, which are largely based on cross-sectional data of one period, focused on specific aspects of the gher farming system, such as, history, present and future challenges of gher farming (Ahmed et al. 2008; Barmon et al. 2005), input use in MV rice production (Barmon et al. 2008a), economic evaluation of MV rice production (Barmon et al. 2007b; 2010), water productivity of MV rice production (Barmon et al. 2008b), women's participation (Barmon et al. 2007a), labor demand and employment of female workers (Barmon et al. 2004a; Rahman and Barmon 2019), child labor participation in prawn fry collection (Ahmed et al. 2009), economics of diversification and production efficiencies (Rahman et al. 2010; Ahmed et al. 2010), impact of freshwater prawn farming on globalization and agrarian change (Ito, 2004), livelihood of prawn farmers (Ito 2002; Ahmed et al. 2008), economic returns of prawn and shrimp farming (Islam et al. 2005), prawn and shrimp marketing (Ahmed et al. 2009; Islam 2008) and energy productivity and energy use efficiency of the gher system (Rahman and Barmon 2012; Rahman and Barmon 2018). Only Ahmed et al. (2008) and Chowdhury et al. (2006) qualitatively discussed sustainability of gher farming system in southwest Bangladesh.

Therefore, given serious concerns and adverse impacts of shrimp-rice farming on soil quality, water quality, environment and biodiversity, it is important to examine the impacts of prawn-rice gher farming system on soil fertility, MV rice productivity and farm income over time. This is because prawn-rice gher system is completely different from shrimp-rice farming system in terms of feeding, cultivation practice and the production environment. For example, brackish water is required for shrimp culture whereas freshwater is needed for prawn culture. Consequently, prawn-rice gher farming system potentially has different impacts on soil quality of the rice field, rice productivity and farm income. But such information is not widely available in the literature.

Therefore, the present study aims to examine the long-term impacts of prawn-rice gher farming system on farm and household income, MV rice productivity and soil fertility in MV rice fields over time covering a 13 year period (2005–2017) by using three rounds of socio-economic survey and soil sample data collected from the same 20 gher farmers operating on 30 gher plots in 2005, 2011 and 2017 from Bilpabla village of Khulna district in southwestern Bangladesh. The detailed information presented in this study will help policy makers and researchers to devise appropriate policies to further develop prawn-rice gher system and agricultural development planning for Bangladesh.

MODES OF SHRIMP/PRAWN PRODUCTION IN BANGLADESH

The southwestern parts of Bangladesh have some natural advantages in shrimp/prawn production. Shrimp/prawn culture is practiced in rivers, tidal channels and the coast over a long time in Bangladesh. The production cost of shrimp/prawn is lower compared to other countries of the world due to the availability of abundant water, land and fry resources. The country possesses one of the world's largest resources of wild shrimp and prawn fry in the Bay of Bengal. In Bangladesh, two types of gher farming are operated, one is brackish water-based shrimp-rice culture and another is fresh water-based prawn-rice culture. Shrimp gher farms are larger in size and scale and need saline water whereas prawn gher farms are comparatively smaller in size and scale and need fresh water. Traditionally, shrimp is cultured in the low lying coastal and peri-coastal regions and prawn is cultured in the upper elevation areas of Bagerhat, Khulna and Satkhira districts.

Traditional Shrimp-rice Culture

The present shrimp culture in Bangladesh still follows the traditional gher farming method. In this method, the flow of saline water into the enclosed areas is controlled by small wooden sluice gates. These sluice gates are opened to allow entry of saline water into the gher from February to

April and at that time the juveniles of various varieties of coastal finfish and post larvae of shrimp which breed in the sea enter the gher. After April, these sluice gates are closed and shrimps are grown until they reach harvestable size. Usually shrimps grow on natural feeds and are ready for harvesting within 4-5 months. In lower regions of Bagerhat, Khulna and Satkhira districts, the local variety of Aman rice (monsoon season) is cultivated from July-December after harvesting of shrimp.

Prawn-rice Joint Culture in the Gher System

In contrast, gher is a physical construction of a piece of agricultural land used for freshwater prawn farming. A gher is a modified rice field having high wide dikes and a canal inside the periphery of the dikes that retains water during the dry season. At the early stage of gher farming, most of the farmers cultivated prawn in monoculture ponds. But recently farmers commonly grow carps with prawn. In addition to rice, vegetables and fruit trees are also grown in this integrated gher farming system.

The gher cycle begins in May/June when the farmers release prawn post larvae into gher. Before this, farmers repair the gher dikes and trenches. This repair work is done almost every year. Farmers use lime during gher preparation to reduce soil acidity. During the growing period, farmers provide supplementary feeds to prawn. Traditionally, only snail meat was used as a prawn feed, but nowadays farmers use a wide range of homemade and commercial supplementary feeds to increase productivity of prawn. Carp fish fingerlings are released into gher in May/June and cultured for nine months until adequate water is retained in the gher. Usually, no specific supplementary feeds are provided for carps. Carps share feeds supplied for prawn. Farmers usually grow vegetables during both winter and summer seasons on the dikes. Some farmers grow vine-type vegetables inside the gher as well.

In the gher farming system, farmers usually grow MV Boro rice (dry winter season) on gher chatal (the land inside the gher) during the winter season between January and April. Farmers irrigate rice field from the surrounding canals inside the gher using mechanical pumps. Gher farmers do not use any type of inorganic fertilizer for MV boro rice production. Farmers provide different types of feed in the gher during prawn and carp production. But prawn and carp do not consume all the supplied feeds. The remaining unused feeds make the rice field naturally fertile and the rice plant absorbs necessary nutrients from within the gher.

MATERIALS AND METHODS

Study Area

Bilpabla is one of the typical villages in Dumuria Thana (sub-district) located about 7 kilometers west of Khulna district and about 310 kilometers south from capital Dhaka. The village is divided by a small river and the households are mainly living on both sides of the river (Figure 2). The land area is defined as medium high in altitude and the soil quality is alluvial, loamy and sandy. Bilpabla village was selected purposively because it is one of the typical villages with dominant gher farming practice. The demographic characteristics of the village are very similar to other villages where prawn-rice gher farming is being practiced. Among 401 households, 332 households own gher farmland and the remaining 69 households do not own any gher farmland in 2003. The average gher farming size was 0.80 ha ~~of~~ which 0.34 ha was own land and 0.46 ha was rented in for gher farming in 2003.

Survey Data

Two sets of data – socioeconomic data of rice and prawn production and soil sample data of the rice field inside the gher were used to examine the impacts of prawn-rice gher farming on soil fertility, MV rice productivity and farm income for the sampled respondents in the study village. Socioeconomic data of rice and prawn production were collected through comprehensive questionnaire and samples of soil were tested in the laboratory. Twenty farmers owning 30 gher plots were randomly selected from Bilpabla village. Soil samples were collected from the mentioned 30 gher plots before and after MV rice production. The three rounds of farm surveys were carried for the same 20 gher farmers during the months of October 2006, October 2012 and October 2018 based on the agricultural cropping year 2005, 2011 and 2017, respectively.

Soil Sampling

In order to assess the impact of gher farming system on soil quality of MV rice fields, the soil samples were collected before and after MV rice cultivation. Each sample of soil is a good mixture of nine sub-samples collected from nine different places of a specific gher plot. The soils were taken from 0-15 cm depth, which represent the cultivated topsoil (BARC 1997). The sampled soils were then placed in transparent polythene bags and then dried well under natural sunshine and labelled numerically for identification. The soil samples were then sieved through a 20-mesh sieve to make the samples suitable for chemical analysis (Hesse 1971; Jones and Case 1990; Petersen 2002). Since the present study aimed at identifying the impact of gher farming on soil quality/fertility, the samples as well as plot numbers were identified with same numerical value at the beginning of rice transplanting and at the harvesting times of MV rice cultivation. After sieving, the labeled samples were sent to the laboratory of the Soil Resource Development Institute (SRDI), Bangladesh located in capital Dhaka for chemical analysis.

As mentioned earlier that soil information were collected before and after MV rice was produced in each year. That is first round of soil information was collected just before MV rice was planted and another round of soil information was collected just after harvesting MV rice from the same plot. By doing so, a total of six rounds of soil information were collected in these three rounds of survey period, 2005, 2011 and 2017. Then the averages of the soil properties of before and after MV rice production cycle for each year to demonstrate changes in these soil information over time.

Soil Analytical Methods

Soil chemical properties were analyzed by routine methods. Soil salinity was measured as electrical conductivity (EC-dS/m; 1:5) using a conductivity meter (Rhoades 1982) and soil pH was measured using a glass electrode pH meter (H_2O, 1:2.5 and pH (KCl, 1:2.5) (McLean 1982). Organic matter (OM) and total nitrogen (TN) were measured using oxidation and the micro-Kjeldahl method, respectively (Mremner and Mulvaney 1982; Nelson and Sommers 1982). Available soil phosphorus (P), and exchangeable potassium (K), calcium (Ca) and magnesium were analyzed using Olsen method (Olsen and Sommers 1982) and ammonium acetate extraction method (Barker and Surh 1982), respectively. Available boron (B), available zinc (Zn) and cupper (Cu) extracted with 0.1 mol/L HCl and easily reducible Mn. However, unfortunately the paramters such exchangeable sodium percentage (ESP) and cation exchange capacity (CEC) were not measured, which are also relevant measures to judge soil salinity.

Analytical Techniques

Computation of Soil Degradation Index (SDI):

Soil degradation refers to temporal changes in the soil health status resulting in a diminished capacity of the ecosystem to provide goods and services for its beneficiaries and deteriorate the capacity to sustain higher yields of agricultural crops (Dumanski and Pieri 1997; FAO 2018). Soil degradation is generally measured by comparing variation of present conditions of certain soil properties in terms of chemical, physical and biological properties under different land use of a particular area with their earlier conditions (Riquier 1978; Adejuwon and Ekande 1988; Islam and Weil 2000; Bremer and Ellert 2004). In this study, the following steps were followed to examine the severity of soil degradation caused by prawn-rice gher farming in the study area. First, the mean values of each of fifteen soil chemical properties of the soil samples of 30 plots of 20 farmers were separately computed for the years 2005, 2011 and 2017. Second, percent change in mean values of each soil property during 2005-2011, 2005-2017 and 2011-2017 were computed. Finally, percent change in values of all fifteen soil properties were added and then averaged to obtain the Mean Soil Quality Change Indicator (MSQI) of prawn-rice gher farming system. It was assumed that larger negative value of MSQI indicates higher degrees of soil degradation due to prawn cultivation and positive value of MSQI indicates improvement in soil qualities of the gher in the study area. Finally, the composite Soil Degradation Index (SDI) of land use for MV rice production in 2005, 2011, and 2017 were computed by calculating the percentage difference in their respective values of MSQI from the base period value of MSQI in 2005. Higher negative differences indicate severe soil degradation and higher positive differences indicate increased soil fertility. Thus, the present study has merged the two conventional methods to assess soil degradation/soil fertility due to MV rice production under prawn-rice gher farming system.

Nonparametric Test: Kruskal Wallis Test

The following Kruskal-Wallis (K-W) test was used to check the differences in real gross revenue, real agricultural income and real household income of prawn-rice gher farming system in the cropping year 2005, 2011 and 2017:

Kruskal-Wallis test,

$$\mathrm{H} = \frac{12}{\mathrm{n(n+1)}}\left[\frac{(\sum \mathrm{R_i})^2}{\mathrm{n_i}}\right] - 3\ (\mathrm{n}+1)\ \mathrm{with}(\mathrm{k}-1)\mathrm{d.f.}$$

The Kruskal-Wallis H test statistic follows Chi-square ($\chi 2$) distribution, n_1, n_2 and n_3 are sample size of prawn-rice gher producers and n is the sum of all prawn-rice producers in cropping year 2005, 2011 and 2017, respectively. $\sum \mathrm{R_i^2}$ is the sum rank of real gross revenue, agricultural income and household income of the prawn-rice producers in 2005, 2011 and 2017 (i =1, 2, 3).

RESULTS AND DISCUSSIONS

Impact of Prawn-rice Joint Culture on Income

Impacts of integrated prawn-rice gher farming system on soil fertility, MV rice productivity and farm income are discussed in this section.

Costs and Returns of Prawn-rice Gher Farming

Total input costs of prawn and MV rice production, gross return, net profit, and agricultural income as well as household income of prawn-rice gher farmers were computed. The total cost items in gher farming include prawn and carp fingerlings cost, various kinds of feed cost, labor, medicine, watching/security cost, seed/seedling cost of rice and vegetables, land preparation cost (bullock power), irrigation, pesticides and fertilizer costs. On the return side, gross return includes revenue from prawn, carp, rice and vegetables. The calculation procedure of variable cost, fixed cost, labor cost, gross revenue, net profit and agricultural income are stated below.

Variable Costs

Variable costs, which consists of the largest share of total cost of gher farming include prawn and carp fingerling costs, feed cost, medicine cost and all labor cost (family supplied labor, permanent and temporary hired labor) for prawn and carp production. These also include seedling costs of rice and vegetables, land preparation cost, irrigation, pesticides and fertilizer costs and labor cost for rice and vegetable production. The variable costs of prawn and MV rice production are presented in Table 1. All variable costs (input costs) of prawn production under gher farming (for the average gher farm size of 0.83 hectare) is estimated at BDT 149,714, BDT 273,655, and BDT 459,152 in 2005, 2011 and 2017, indicating that the nominal input costs has increased by 83% in 2011 from 2005 and 68% in 2017 from 2011, respectively. The main reason is that all input costs have significantly increased (mainly prawn fingerling and feed costs) over the period. Similarly, the total input costs of MV rice production under gher farming have also increased by 76% in 2011 from 2005 and 66% in 2017 from 2011, respectively, mainly because of higher inputs price.

Fixed Costs

The fixed costs of gher farming are considered as maintenance cost of gher farming, preparation cost of monitoring house, depreciation cost of construction of gher farming, and land rent. The land rent is considered as the amount paid by the tenant farmer to the landlord. In case of own farmers, the land rent is calculated on the basis of the present value of land rent that the own farmers could have earned by renting out their land. The components of fixed costs are also presented in Table 1. It shows that total fixed cost has increased by 52% from 2005 to 2011 and 61% in 2017 from 2011, respectively. The main reason was that the socio-economic status of gher farmers have improved simply because of the profit generated from gher farming. As a result, the family labor also engaged in working in their owned gher plots. They hire labor for maintaining and repairing dikes and uprooting grass on the sides of gher plots. Even though per unit rent of gher plots doubled in 2011 and 2017, the amount of rent in total fixed cost remains very small. The fixed costs per unit gher plot has increased significantly in 2017 because of higher opportunity cost of family supplied male and female labor and rent of gher plots in the study area.

Labor Cost

Labor cost, which was one of the main cost items in gher farming, includes cost of family labor, permanent and temporary hired labor. The family labor cost was calculated on the basis of opportunity cost at the current market rate of hired labor. The hired labor cost was simply the local agricultural wage. Most of the labor cost was incurred in harvesting of prawn and cleaning the gher. The labor costs of prawn and MV rice production are presented in Table 1. The wage rate of temporary and permanent hired labor for male and female both for prawn and MV rice production has increased significantly in 2011and 2017 as compared to 2005. The wage rate for hired male labor was BDT 120/day in 2005, whereas it increased to BDT 250/day and BDT 500/day in 2011 and 2017, respectively.

Gross Revenue and Net Profit

Gross revenue is calculated by multiplying the total volume of production of the farm by the farm-gate price. Net profit is calculated by subtracting total production cost (fixed and variable costs) from gross revenue. Total agricultural income of the gher farmers who cultivated their own gher plots includes net profit of gher farming, opportunity cost of family labor and land cost, while the gher farmers who rented in the gher plots from the landlords includes net profit of gher farming and opportunity cost of family labor for rented farmer. Total revenue and net profit of gher farming are shown in Table 1. The table shows that total gross revenue of joint prawn-rice gher farming was BDT 333,976, BDT 552,313 and BDT 826,694 in 2005, 2011 and 2017, respectively, indicating that the nominal gross revenue has increased by 65% in 2011 from 2005 and 50% in 2017 from 2011, respectively and it was the collective contribution of all inputs used in joint prawn-rice gher farming to produce prawn and MV paddy. The amount of net profit of joint prawn-rice production under gher farming was BDT 144,591, BDT 218,395 and BDT 270,593 in 2005, 2011 and 2017, respectively, which indicates that ~~the~~ nominal profit has increased by 51% from 2005 and 24% in 2017 from 2011, respectively. However, when real profit was computed by deflating nominal values using national consumer price index, the real net profit has decreased from BDT 144,591 in 2005 to BDT 139,469 in 2011, a 3.5% decrease from 2005 and BDT 123,075 in 2017 a 12% from 2011, respectively, but the difference is not statistically significant.

Household Income of Gher Farmers

In general, there are three main sources of income of agricultural households in Bangladesh. These are: profit from agricultural production, agricultural labor wage income, and income from non-agricultural activities. The agricultural profit is the sum of crop income and income from livestock and poultry. Similarly, agricultural labor wage income includes both family labor used on own farm and labor sold to other farms. And non-agricultural income can be decomposed into earnings from self-employment, wage received in rural non-farm labor markets and remittances from household members working in urban areas (Renkow 2000).

The agricultural income, the components and percentage (%) share of household income are presented in Table 2. It is evident that agricultural income remains the principal source of income for households of the sampled gher farmers, which has increased considerably over the sampled period in nominal terms. The amounts of agricultural wage, opportunity cost of family members, and off-farm income were almost the same in the contribution to total household income. The agricultural wage income accounts for only 5 percent for gher farmers, indicating that family members enjoyed more leisure time and engaged in other off-farm activities. The amount of opportunity cost of gher land was contributed about 9 percent, 11 percent and 13 percent to net household income in 2005, 2011 and 2017, respectively. The percentage contribution of opportunity cost has increased slightly during the period simply due to increase in market value of main output prawn. The income of livestock was estimated at about 9 percent, 10 percent and 7 percent to net household income in 2005, 2011 and 2017, respectively. The contribution of off-farm (about 2 percent) and homestead gardening (less than 1 percent) income to net household income were very negligible. Annual total nominal household income of gher farmers was increased from BDT 214,843 in 2005 to BDT 341,527 in 2011 and BDT 420,846 in 2017. This indicates that nominal total household income has increased by 59% in 2011 from 2005 and 23% in 2017 from 2011, respectively. However, the real household income has increased slightly by 1.52% in 2011 from 2005 and decreased by 12% in 2017 from 2011, respectively. Annual per household income in rural areas in Bangladesh was BDT 115,770 in 2011 and BDT 160,236 in 2017 (BBS, 2011, 2018). Table 2 shows that the total nominal household income of gher farmers is nearly 200% higher than the income of rural areas of Bangladesh. The table also shows that the nominal agricultural income has contributed about 65% to nominal household income during the period 2005 to 2017. The nominal agricultural income has increased by 51% in 2011 from 2005 and 24% in 2017 from 2011, respectively. Therefore, it can be concluded that the prawn-rice gher farming system has increased total nominal household income over the study period in this area as compared to other rural areas in Bangladesh.

Changes in Real Income from all Sources

In this section, an attempt is made to determine the changes in real income gained from gher farming system and other sources for three cropping years 2005, 2011 and 2017.

Nominal and real total gross revenue from gher farming, agricultural income and total household income of gher farmers in cropping years 2005, 2011 and 2017 are presented in Table 3. It is evident from the Table 3 that although nominal values of these three sources of income have changed substantially, the real values of these incomes did not change significantly over the 13-year period under consideration. This is mainly due to high rate of inflation persisting in Bangladesh which wipes out any gain in income over time. However, it is encouraging to note that the real income from all sources for gher farming household is stable over time. Besides, earlier studies found that gher farming system has generated more agricultural income as well as household income compared to traditional and MV rice producers in the southwest Bangladesh (Barmon et al. 2004b).

IMPACT OF GHER FARMING ON MV RICE PRODUCTIVITY (YIELD/ha)

Agricultural productivity is a measurement of the ratio of agricultural outputs to agricultural inputs. In this study, MV rice productivity mainly depends on irrigation facility, application of chemical fertilizers, varieties of seed used and the production environment. The per hectare yield of MV rice was used as the principal measure of MV rice productivity.

The actual yields (kg/ha) of MV rice under prawn-rice gher and year-round MV rice farming system in 2005, 2011 and 2017 are presented in Table 4. Table 4 reveals that on average, the yield of MV rice in gher farming system first declined in 2011 but then increased in 2017. However, overall the decline is significant as compared to the base year of 2005. In contrast, on an average, the yield of MV paddy in conventional year-round rice farming increased from 3,997 kg/ha in 2005 to 4,425 kg/ha in 2017 in Lebubinia village located next to Bilpabla village (Barmon et al. 2010 and Field survey 2018).

IMPACT OF GHER FARMING SYSTEM ON SOIL FERTILITY

Changes in Soil Properties and Soil Fertility

Prawn-rice gher farming system can potentially affect soil properties of MV rice production in several ways. Usually, chemical fertilizers, pesticides and irrigation are the main necessary inputs for MV rice production. In conventional system, chemical fertilizers are the main source to enhance soil fertility for MV rice production, whereas in the gher farming system, nutrients from leftover feeds of prawn production, faeces/excretion of prawn and carp, algae and fungi are the main source of soil nutrients for MV rice production. Even though transformation of rice fields into prawn-rice gher farming reduces 40% of the total rice field area, increased MV rice productivity and fodder (straw) due to improve soil quality make up for the shortfall in land area. Changes in soil properties of rice field of gher farming are presented in Table 5.

Soil pH

The term pH refers to alkalinity or acidity of a growing media water solution. Soil pH and base saturation are the important chemical properties that influence soil nutrient availability and plant growth and the activities of soil microorganisms and organic matter decomposition. All plants are not able to tolerate acidic or alkaline soils. Rice crops usually prefer slightly low acidic soils compared to other crops. On average, the mean pH of soil in rice field in gher farming system was estimated at 7.20 in 2005. However, the corresponding figures changed to 6.93 in 2011 and 6.99 in 2017, respectively. Consequently, the pH level of soils in the mid paddy field of joint prawn-rice gher farming system remains neutral in MV paddy cultivation.

Electrical Conductivity (EC)

Electrical conductivity (EC) is an important soil property related to salinity and is often used for delineating other soil properties. EC measures the amount of total dissolved salts in the water. It appears from Table 5 that the mean values of EC were 5.66 dS/m period in 2005 which changed to 5.52 dS/m in 2011 and 5.80 dS/m in 2017. Most of the gher farms are located in the southwestern part simply because of compatible production environment of shrimp/prawn and its soils are comparatively more saline than other areas of Bangladesh. As mentioned earlier that shrimp-rice gher frams are located nearer to the sea and require brackish water, whereas prawn-rice gher farms are located far from sea and require fresh water. Consequently, soils in shrimp-rice farms are more saline than prawn-rice farms. The mean values of EC is slightly higher than the critical limit of EC (4 dS/m) in the study area indicating that soils are slightly saline but at the tolerance level of MV rice production (BARC 2018; SRDI 2010). The implication of the result is that under the joint prawn-rice gher farming system, although accumulation of salt takes place during harvesting time as compared to the beginning of transplanting but the average level of salt accumulation is slightly higher, implying that rice fields do not suffer too much from this slightly high level of soil salinity problem that could not hamper plant growth substantially (SRDI, 2010). The main reason is that the rice areas of gher plots get washed away during the rainy season when prawn is cultured. As a result, the natural salt did not accumulate in rice fields as happened with prawn farming (Barmon et al. 2010).

Total Nitrogen (%)

Nitrogen is an essential macronutrient for plant function. Nitrogen is also a major component of proteins, hormones, chlorophyll molecule, vitamins and enzymes, which enables the plant to capture sunlight energy by photosynthesis, driving plant growth and grain yield. The availability of optimal nitrogen for crop production influences crop yield and nitrogen deficiencies reduces yield. The critical value of total nitrogen (%) of clay soil in wetland rice field in southwestern Bangladesh is 0.12 (BARC 2018). The total nitrogen (%) content in the soil of mid-rice fields of joint prawn-rice gher farm was estimated at 0.41 in 2005 which changed to 0.46 in 2011 and 0.47 in 2017 which were significantly higher than the critical level. The implication is that the left-over feed, azolla and algae enhance total nitrogen availability, which potentially improves MV rice productivity to some extent (Barmon et al. 2010; Islam et al. 2015).

Organic Matter (OM) (%)

Organic matter (OM) is an important organic component of soil, serving as a reservoir of nutrients and water in the soil, provides soil aggregation, increases nutrient exchange, retains moisture, reduces surface crusting and increases water infiltration into water (Russell 1977; Bot and Benites 2005; Craswell and Lefroy 2001). After harvesting of rice grain, the rest of the rice plant (root and shoot) remain in the rice field along with naturally grown aquatic ferns (azolla) and algae in in the mid paddy field decompose into the soil and converted into OM (Barmon et al. 2010). The critical value or standard level of one of the soil fertility indicator organic matter (OM) (%) in soil is 5. Higher value of OM (>5%) indicates increased soil fertility and productivity, and lower value (<5%) indicates soil degradation (BARC 2018). . On average, the total organic matter in the soils of rice field in gher farming system was computed at 11.74 in 2005, which changed to 11.87 in 2011 and 11.86 in 2017, which were significantly higher than the standard level of OM (>5%) for quality soil for crop production (BARC 2018). This indicates that over the years OM (%) content in the soil of prawn-rice gher farming remained the same and the level is naturally much higher which is potentially more beneficial to MV rice productivity. However, it is worth mentioning that OM content decreased more rapidly in MV rice fields under shrimp-rice farming system, possibly going below the standard level recommended by BARC, thereby adversely affecting MV rice productivity in coastal region of Bangladesh (Ali 2004; 2006).

Carbon Nitrogen (C/N) ratio

Carbon-nitrogen ratio refers the chemical relationship between carbon (C) and nitrogen (N) which is an important part of understanding soil quality because it determines decomposability of soil organic matter. Carbon Nitrogen (C/N) ratio of soils was almost same in the gher farming system in 2005, 2011 and 2017. The carbon-nitrogen (C:N) ratio lies between 8:1 to 30:1, however, the critical limit is 10:1 (BARC 2018). The C/N ratio was about 13:1 in the soil MV paddy cultivation during the period 2005 to 2017, which is a very satisfactory level of the extent of nitrogen immobilization in soils for MV paddy production in joint prawn-rice gher farming system. This indicates that the gher farming system has substantially improved soil quality, which enhanced MV rice productivity in the study area.

Available Phosphorus (P)

Phosphorus is essential for plant growth, seed germination, photosynthesis, protein formation and metabolism in plants and flower and fruit formation. Deficiency symptoms are purple stems and leaves, maturity and growth retardation, premature drops and poor yield of fruits and flowers. Table shows that the mean level of available phosphorus varies from 10.90 μg/g soil to 11.17 μg/g during the period, which is higher than the critical limit 7 μg/g soil (BARC 2018). This indicates that soils of gher plot retains available phosphorus suitable for MV paddy cultivation for the next year.

Total Carbon (C)

Soil organic carbon is the biggest part of the soil organic matter and it is considered as the most important indicator of soil quality and productivity through its positive effects on soil structure, water storage capacity and nutrient supply (Milne et al. 2010; Barmon et al. 2010). Soil organic carbon also plays vital role in soil formation and it is strongly correlated with soil organic nitrogen, which help to improve soil productivity in cropland (Gaiser and Stahr 2013). Table 5 shows that on average, the available total organic carbon (C) in the soils of rice field in gher farming system was computed at 76.86 g/kg, 77.42 g/kg and 78.83 g/kg in 2005, 2011 and 2017, respectively. The implication is that the total carbon increased very slowly over the years 2005 to 2017, which indicates that soils in gher farming system became more fertile over the years.

Potassium (K), Calcium (Ca), Zinc (Zn), Sulpher (S), Manganise (Mn), Cupper (Cu) and Boron (B)

The values nutrient of K, Ca, Zn, S, Mn, Cu and B are presented in Table 5. It shows that the estimated mean values of K, Ca, Zn, S, Mn, Cu and B were almost the same in 2005, 2011 and

2017 under the joint prawn-rice gher farming system. This indicates that the gher farming system maintains potassium (K), calcium (Ca), zinc (Zn), sulpher (S), manganise (Mn), cupper (Cu) and boron (B) in soils over time. The main reason is that farmers apply various types of feeds during prawn and carp production during the rainy season because they believe that the leftover feeds and naturally grown aquatic ferns (azolla) and algae in in the mid paddy field of gher farming make the soil fertile for MV rice production as revealed by the farmer during field surveys (Field survey, 2018), which is not possible in traditional year-round MV rice production system (Barmon 2010).

Accumulation of N, P, and S

Chemical fertilizers such as urea, muriate of potash (K_2O), triple super phosphate (TSP), gypsum and zinc sulfate are the main inputs along with irrigation and MV rice seeds for traditional year-round MV rice production. As mentioned earlier that farmers provide various types of supplementary feed such as homemade feed, meat of mud snail, and processed feed during the growth period of prawn (May-November). The ingredients of homemade feed include oilcakes, polished rice, wheat bran, wheat, fish meal and other feeds in fixed proportions. According to the perceptions of farmers revealed during field surveys, farmers believe that nutrients from leftover feeds of prawn production, feces of prawn and carp fish, decompose naturally into azolla, and algae which release nitrogen (N), phosphorus (P) and sulfur (S) in soils in the gher which make the soil more fertile. Consequently, farmers apply very small amount of urea, muriate of potash, triple super phosphate, gypsum and zinc sulfate for MV rice production under the joint prawn-rice gher farming system. In contrast, sulfide rich tidal water is required to cultivate shrimp and MV rice in the joint shrimp-rice gher farming, which accumulate more sulfur (S) than the critical level in the mid rice field which reduces MV rice productivity over time (Ali 2004 and 2006).

Soil Acidity and Salinity Status

The soil samples collected in 2005, 2011 and 2017 showed that soil pH in MV rice fields of the sampled gher plots were almost same over the years and the values of pH is close to 7.0, which is neutral, implying that soil acidity did not increase in rice field due to prawn culture in gher farming in the study area. The main reason is that MV boro rice production starts from the end of December and finishes at the end of April in gher farming system. In gher farming system, water drains into canals or sometimes a small amount (6-10 inches) of water remains on the mid-field (*chatal*) at the end of December depending on the location and altitude level of gher plots. At that time, farmers prepare land to transplant MV rice on the topsoil. As the topsoil of the mid-field of gher is clay soil, no irrigation is required for soaking of the topsoil for transplantation. The topsoil retains adequate amount of water for MV rice transplantation. Sometimes, when water drains into the canal and the topsoil becomes dry, irrigation is required to soak the land to prepare for MV rice transplantation. Recently, farmers make new canals inside gher plots and fill the old canals using soils of new canals. The transformation and moving of soils improve soil fertility to a level optimum for MV rice as well as prawn production. Farmers believe that if the position of canals shifts every 3-4 years, then soils become more fertile for crop production. In contrast, ground water irrigation is required to cultivate MV rice under shrimp-rice gher farming and soils in the rice fields become more acidic and increase over the years due to prolonged trapping of tidal water in shrimp ponds which allow sulfur from the sea water to precipitate at the bottom of the ponds and at the end of rice cultivation the exposed sulfide deposits are oxidized and release sulfuric acid to the soil which increases its acidity and salinity (Ali 2006).

On the other hand, the values of EC of soils in the rice plots under prawn-rice gher farming were almost the same over the period 2005, 2011 and 2017, which implies that soil salinity did not increase significantly in prawn-rice gher farming, although the actual values are >4 dS/m which indicates presence of some salinity (BARC 2018). The main reason is that the farmers in prawn-rice gher farming irrigate rice fields from canals which retain adequate amount of surface water. Moreover, the rice fields in prawn-rice gher farming system washes out harmful excessive salt and sulphur thereby assisting in reducing the extent of soil salinity that could seriously affect plant growth. In contrast, low-lift pump irrigation is used to cultivate MV rice production in shrimp-rice gher farming along with tidal sea water. The salinity of soils of rice fields in shrimp-rice gher system increased over the years due to prolonged trapping of saline tidal water in shrimp ponds (Ali 2004 and 2006).

MSQI and SDI of Soil Status

The mean soil quality index (MSQI) and soil degradation index (SDI) are used to assess soil quality of rice fields in prawn-rice gher farming system in 2005, 2011 and 2017 and the values of MSQI and SDI are presented in Table 6. The computed values of MSQI of land use for MV rice production under prawn-rice gher farming system were 5.04, 5.31 and 10.80 for the periods 2005-2011, 2011-2017 and 2005-2017, respectively. This indicates that the production structure and process of feeding for prawn production and irrigation system of MV rice cultivation under the prawn-rice gher farming system has substantially improved soil quality over the years from 2005 to 2017. Similarly, the values of SDI of the MV rice production during the periods 2005-2017 and 2011-2017 were 5.32 and 114.20, respectively, which are also positive thereby indicating that the soil quality of rice fields in prawn-rice gher farming system has improved over time from 2005 to 2017. Therefore it may be concluded that the joint prawn-rice gher farming system is relatively sustainable in terms of improving soil fertility levels of the MV paddy field located within the gher system.

CONCLUSIONS AND POLICY IMPLICATIONS

The present study evaluated the impacts of joint prawn-rice gher farming system in sustaining MV rice productivity, soil fertility and income of the farmers from Bilpabla village, Khulna district in southwestern Bangladesh covering a 13-year period (2005-2017). Results reveal that the parwn-rice gher farming system has significant impact on both agricultural income and total household income. Not only the nominal income increased significantly, but the real income remained stable over time implying that the gher farmers are able to offset the high inflationary pressure of the economy. The gher farming system also has substantial positive impacts on soil quality. The values of mean MSQI and SDI indicates that soil quality of the rice-fields within the gher plots has improved over the years, thereby indicating its sustainability in terms of soil quality. According to the experiences and perception of farmers, this was made possible due to washing out excessive salts and sulfur of soils during the rainy season and the use of leftover feeds and sometimes decomposition of naturally grown aquatic ferns (azolla) and algae in gher plot in prawn production before transplanting of paddy seedlings, which serves as organic source of soil nutrients, e.g., nitrogen, soil organic matter, phosphorus, potassium and other nutrients to fertilize the soils in rice-fields for MV rice production with very little or no use of inorganic fertilizers (Field survey 2018; Barmon et al. 2010). Although MV rice productivity in prawn-rice gher farming system of the sampled farmers declined in 2011 and 2017 from its 2005 level, it is still significantly higher than the traditional year-round MV rice cultivation practiced in Bangladesh. In short, the prawn-rice gher farming system is sustainable over the long run as it enabled farmers to stabilize their real income and enhanced soil quality of rice-fields which allowed to keep MV rice productivity in the gher system higher than the conventional MV rice farming system over time. Policy implication includes research on developing varieties of MV rice that are specifically suited to gher farming system and development of commercial feed and market for prawn which is the main income generating component of this joint prawn-carp-rice enterprise for future growth of agriculture and boosting income of gher farmers in southwestern region of Bangladesh.

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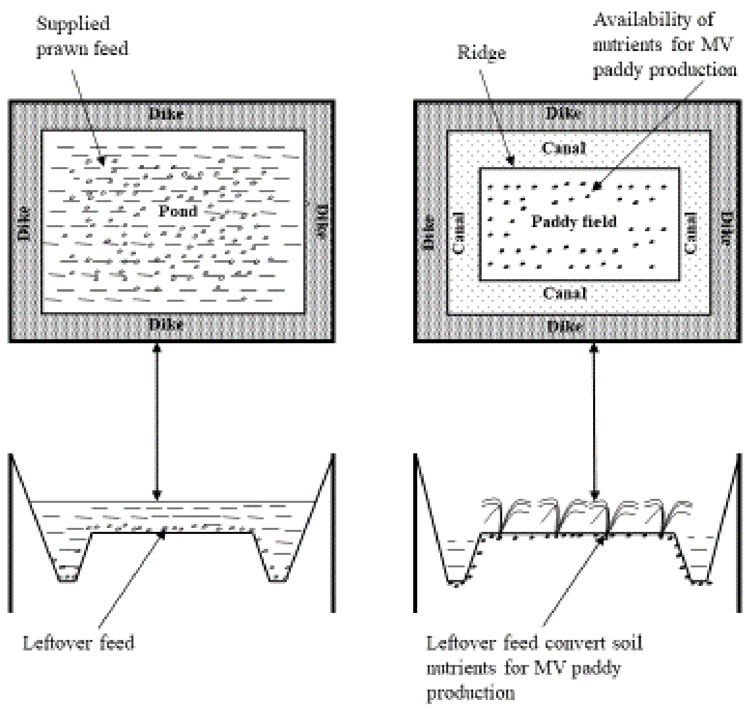
Figure 1. Diagram of RPG system in rainy and winter season and irrigation system and soil fertility process for MV paddy production.



a) Gher farming in rainy season

b) Gher farming in winter season

Figure 2. The location of study area and rice-prawn gher farming

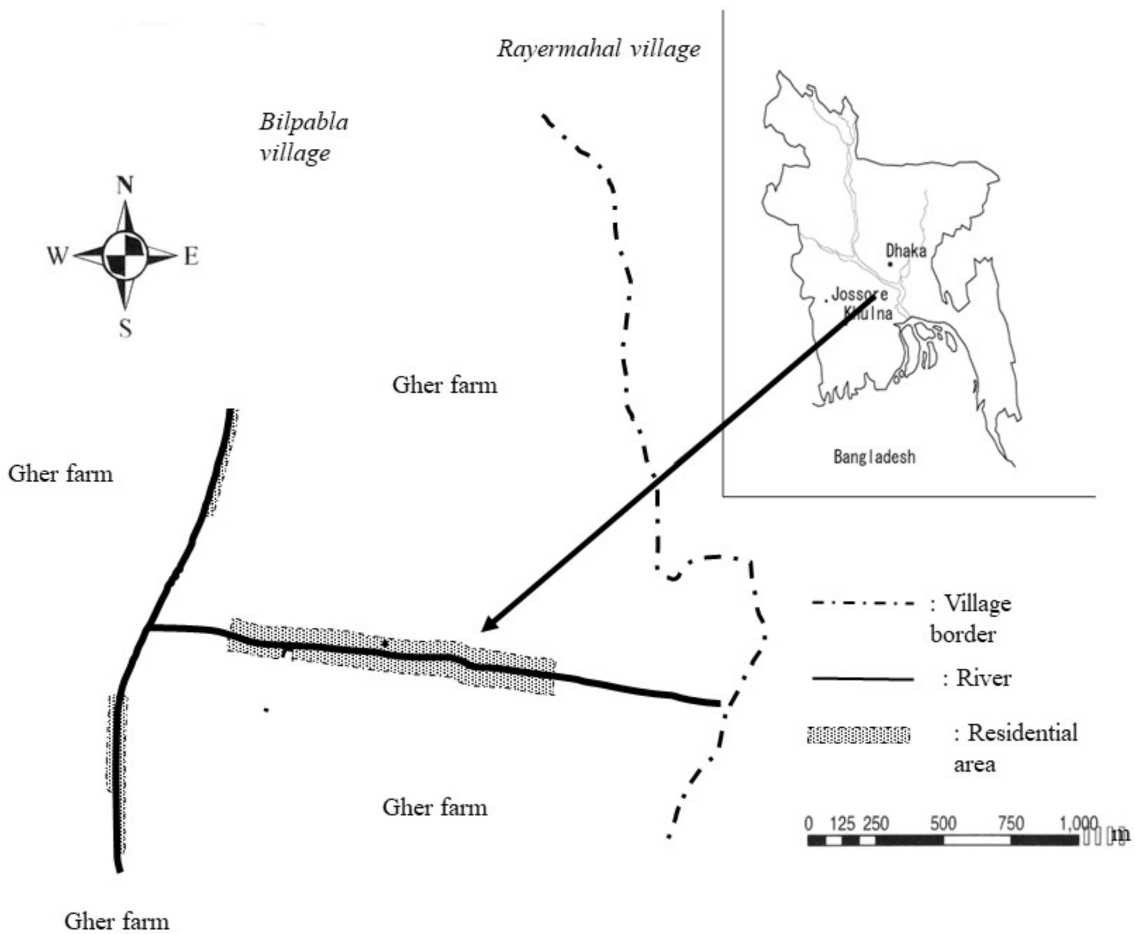


Table 1. Production costs and returns of prawn-rice gher (PRG) farming

Particulars	(2005)	(2011)	(2017)
A. Variable costs of prawn and fish production:	(Taka)	(Taka)	(Taka)
(i) Prawn fingerlings	59,630	52,246	55,698
(ii) Carp fish fingerlings	2,140	15,025	17,040
(iii) Feed	56,275	146,856	279,760
(iv) Medicine	1,617	2,608	4,150
(v) Hired labor	18,734	34,630	68,590
Sub total	**138,396**	**251,365**	**425,238**
B. Variable costs of paddy and vegetables production:			
(i) Paddy seed/seedlings	1,005	1,841	1,936
(ii) Vegetables seed/seedlings	126	211	473
(iii) Land preparation (bullock)	1,802	1,825	2,215
(iv) Hired labor	5,608	12,896	21,865
(v) Irrigation	515	1,905	3,135
(vi) Pesticides	1,081	1,215	1,525
(vii) Fertilizer	641	1,492	1,905
(viii) Machinery cost	540	905	860
Sub Total	**11,318**	**22,290**	**33,914**
C. Total variable costs (A+B)	**149,714**	**273,655**	**459,152**
D. Fixed costs:			
(i) Depreciation cost of gher preparation	1,599	2,976	4,024
(iii) Opportunity cost of land	19,525	37,650	55,100
(iv) Opportunity cost of family labor	13,747	12,937	30,925
(v) Land rent	4,800	6,700	6,900
Total fixed costs	**39,671**	**60,263**	**96,949**
E. Total costs (variable and fixed costs) (C+D)	**189,385**	**333,918**	**556,101**
F. Revenue from prawn and fish:			
(i) Prawn	274,275	444,740	669,863

(ii) Carp fish	24,420	54,475	84,980
G. Revenue from paddy and vegetables:			
(iii) Paddy	31,825	45,728	62,358
(iv) By-product of paddy	2,228	5,720	6,925
(v) Vegetables	1,228	1,650	2,568
H. Total revenue (F+G)	**333,976**	**552,313**	**826,694**
I. Net profit (H-E)	**144,591**	**218,395**	**270,593**
CPI	**100**	**157**	**220**
J. Real net profit	**144,591**	**139,469**	**123,075**

Source: Field Survey, 2006, 2012, 2018.

Notes: (i) 1US$=83.60 Taka, October, 2018.

(ii) Surveyed average gher farm size was 0.90 hectare.

(iii) Sample size was 20.

(iv) Depreciation of construction of gher and monitoring house were calculated by the straight-line method. In this method, depreciation is to divided total expected depreciation equally among the expected number years of the life of the gher. It works fairly well for purpose of analyzing the farm business (Hopkins and Heady, 1955). On the basis of the farm survey data, the economic life of gher farming was considered as 25 years.

Table 2. Household income (taka) of rice-prawn gher (RPG) farmers

Sources of income	(2005)	(2011)	(2017)
(i) Profit/agricultural income	144,591	218,395	270,564
	(67.30)	(63.95)	(64.29)
(ii) Opportunity cost of family labors	13,747	35,600	30,925
	(6.40)	(10.42)	(7.35)
(iii) Opportunity cost of land	19,525	37,650	55,100
	(9.09)	(11.02)	(13.09)
(iv) Agricultural wage (male and female)	12,155	16,175	24,745
	(5.66)	(4.74)	(5.88)
(vi) Livestock	19,557	23,950	28,350
	(9.10)	(7.01)	(6.74)
(vii) Off-farm income	4,200	7,680	8,705
	(1.95)	(2.25)	(2.07)
(viii) Homestead gardening	1,069	2,077	2,457

	(0.05)	(0.06)	(0.05)
Total household income (Tk.)	**214,843**	**341,527**	**420,846**
% contribution of Agricultural income to Household income	**67.30**	**63.95**	**64.29**
CPI	**100**	**157**	**220**
Real household income (Tk.)	**214,843**	**218,102**	**191,415**

Source: Field survey, 2006, 2012, 2018.

Note: The figures in parentheses indicate percentage (%) share to household income.

Table 3. Comparison of total revenue, agricultural family labor income, agricultural income, off-farm income and total household income in 2005, 2011 and 2017

Particulars	(2005)	(2011)	(2017)	Kruskal Wallis statistic
(i) Total gross revenue	333,976	552,313	826,694	
(ii) Agricultural income	144,591	218,395	270,564	
(iii) Household income	214,843	341,527	420,846	
CPI	100	157	220	
Real gross revenue	333,976	352,713	376,009	0.13
Real agricultural income	144,591	139,469	123,062	0.16
Real household income	214,843	218,102	191,415	0.87

Source: Field survey, 2006, 2012 and 2018.

Table 4. Actual yield (kg/ha) of MV paddy in PRG and YRMV farming system in 2005, 2011 and 2017

Cropping year	Prawn-rice gher (PRG) farming					Year-round MV (YRMV)
	Mean	SD	Min	Max	Rank sum	Mean
2005	5,188	416	1,580	4,346	829.0	3,997[a]
2011	4,720	398	3,769	5,399	443.5	Na
2017	4,841	428	3,769	5,531	557.5	4,425[b]
Kruskal-Wallis statistic	12.859***					

Sources: Field survey, 2006, 2012, 2018.
Note: (1) *** denotes statistically significant at 1% level.
(ii) Na indicates not available of data.
Source: (a) Barmon et.al. (2010); (b) Field Survey, 2018.

Table 5. Descriptive statistics of soil fertility status (0-15cm) in rice-prawn gher farming system in Bilpabla village, Khulna district

Soil property	2005				2011				2017			
	Mean	SD	Min	Max	Mean	SD	Min	Max	Mean	SD	Min	Max
pH	7.20	0.50	5.60	8.50	6.93	0.46	5.30	7.60	6.99	0.30	5.35	6.80
EC (ds/m)	5.66	0.59	3.39	8.94	5.52	0.54	1.71	9.25	5.80	0.31	3.80	6.53
Total Nitrogen (%)	0.41	0.05	0.24	0.68	0.46	0.10	0.19	0.69	0.47	0.06	0.29	0.68
Organic matter (%)	11.74	0.50	6.26	15.78	11.87	0.97	3.80	13.75	11.86	0.68	7.23	12.61
Potash (K)	1.11	0.14	0.62	2.25	1.11	0.32	0.25	2.31	1.20	0.29	0.39	1.83
Calcium (Ca)	29.59	0.92	15.50	40.90	30.14	1.85	17.81	39.72	32.79	2.28	15.55	45.85
Phosphorus (P)	10.90	0.90	2.21	35.50	11.17	1.73	2.30	17.75	10.97	0.81	3.18	11.45
Zinc (Zn)	1.88	0.42	0.70	6.31	1.90	0.39	0.30	3.37	2.16	0.40	0.56	3.50
Sulpher (S)	204.35	5.90	49.10	396.10	226.30	82.70	44.70	390.00	237.30	83.17	44.70	454.70
Manganese (Mn)	92.46	1.91	44.70	192.80	101.19	3.31	49.05	193.59	107.39	4.41	55.20	207.80
Boron (B)	2.46	0.30	1.44	3.87	2.46	0.32	0.26	2.38	2.57	0.22	0.58	2.26
Copper (Cu)	10.27	5.35	4.92	18.12	11.95	1.52	7.72	18.48	12.59	1.50	8.51	22.19
Total Nitrogen (N)	26.56	2.96	2.20	9.50	5.68	0.52	4.39	6.98	6.68	0.54	5.43	8.05
Total Carbon (C)	76.86	9.33	26.50	144.00	77.42	4.27	52.22	69.45	78.83	3.71	39.35	84.00
C/N ratio	12.60	0.63	11.00	15.00	12.76	1.55	9.54	13.89	13.09	1.52	8.33	17.33

Source: Laboratory experiment, 2006 and 2012, and 2018.

Notes: 1) Soil sample size was 30 from 20 gher farmers.

2) SD indicates standard deviation.

Table 6. Mean Soil Quality Index of MV Paddy Production in joint Rice-prawn Gher Farming System

Soil Properties	2005	2011	2017	2005-2011 (% Change)	2011-2017 (% Change)	2005-2017 (% Change)
pH	7.20	6.93	6.99	-3.75	0.87	-2.92
EC (ds/m)	5.66	5.52	5.80	-2.47	5.07	2.47
Total Nitrogen (%)	0.41	0.46	0.47	12.20	2.17	14.63
Organic matter (%)	11.74	11.87	11.86	1.11	-0.08	1.02
Potash (K) (mg/100g soil)	1.11	1.11	1.20	0.00	8.11	8.11
Calcium (Ca) (mg/100g soil)	29.59	30.14	32.79	1.86	8.79	10.81
Phosphorus (P) (µg/g soil)	10.90	11.17	10.97	2.52	-1.79	0.69
Zinc (Zn) (µg/g soil)	1.88	1.90	2.16	1.06	13.68	14.89
Sulpher (S)(µg/g soil)	204.35	226.30	237.30	10.74	4.86	16.12
Manganese (Mn) (µg/g soil)	92.46	101.19	107.39	9.44	6.13	16.15
Boron (B)(µg/g soil)	2.46	2.46	2.57	0.00	4.47	4.47
Copper (Cu)(µg/g soil)	10.27	11.95	12.59	16.36	5.36	22.59
Total Nitrogen (N) (g/kg)	4.56	5.68	6.68	24.56	17.61	46.49
Total Carbon (C) (g/kg)	76.86	77.42	78.83	0.73	1.82	2.56
C/N ratio	12.60	12.76	13.09	1.27	2.59	3.89
MSQI	-	-	-	5.04	5.31	10.80
SDI	-	-	-	-	5.32	114.20

Source: Laboratory experiment, 2006 and 2012, and 2018.

Notes: (i) Soil sample size was 30 from 20 gher farmers.

(ii) SD indicates standard deviation.